Investigation
of … ious losses in a Steam Engine

Paul Munoz
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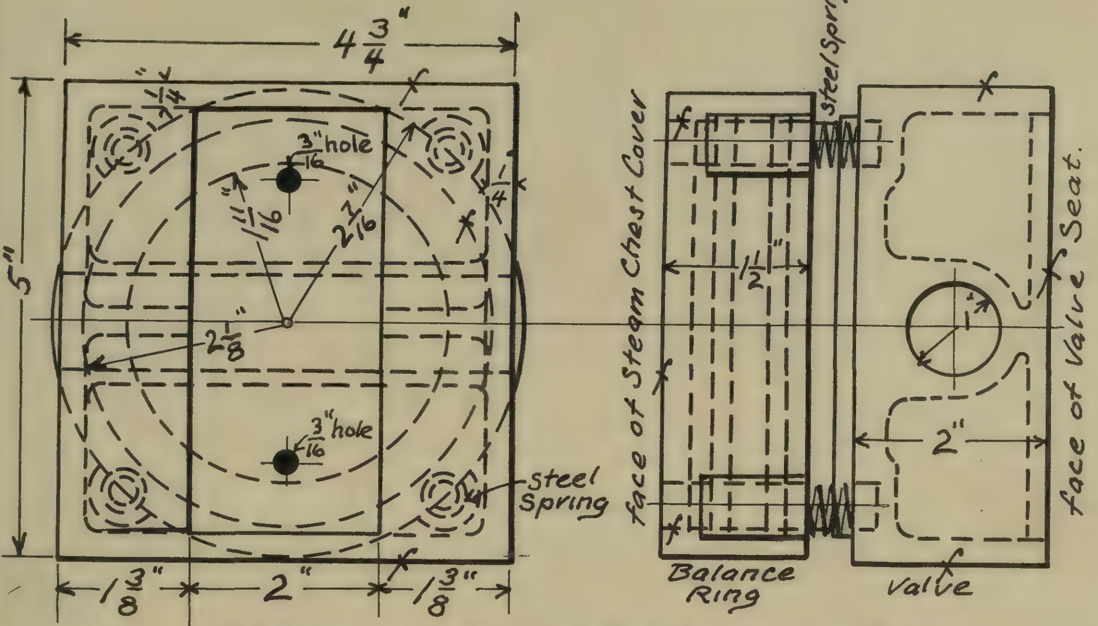
The tests described in this thesis are an attempt to analyse some of the various losses which of necessity occur in a slide valve steam engine.

The engine on which the ~~x~~tests were made is a Sturtevant Blowing engine running a three-quarter housed centrifugal fan keyed directly to the shaft of the engine. The valve on this engine is a common D slide valve with a cylindrical balance ring on the back. This balance ring fits on a cylindrical projection on

Fig. 1



Detail of Valve & Balance Ring
of Sturtevant Blowing Engine
Scale 6"=1'

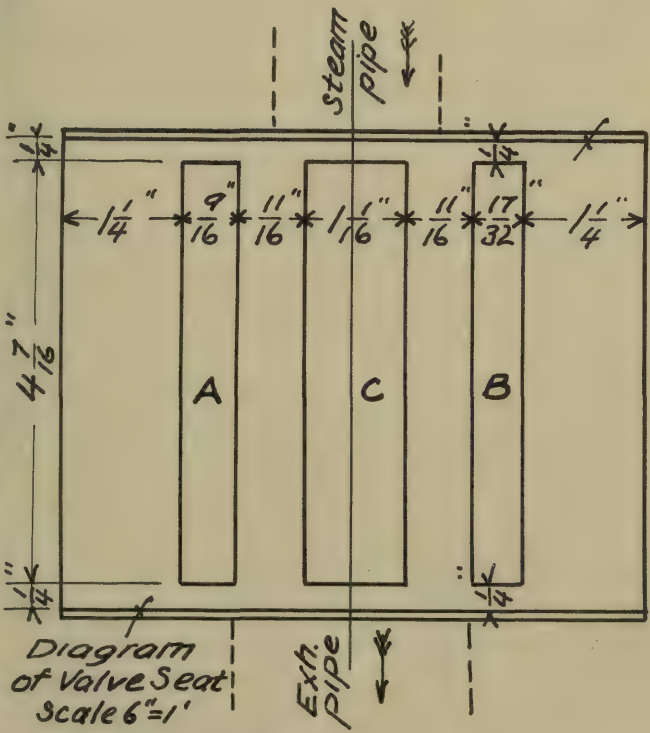
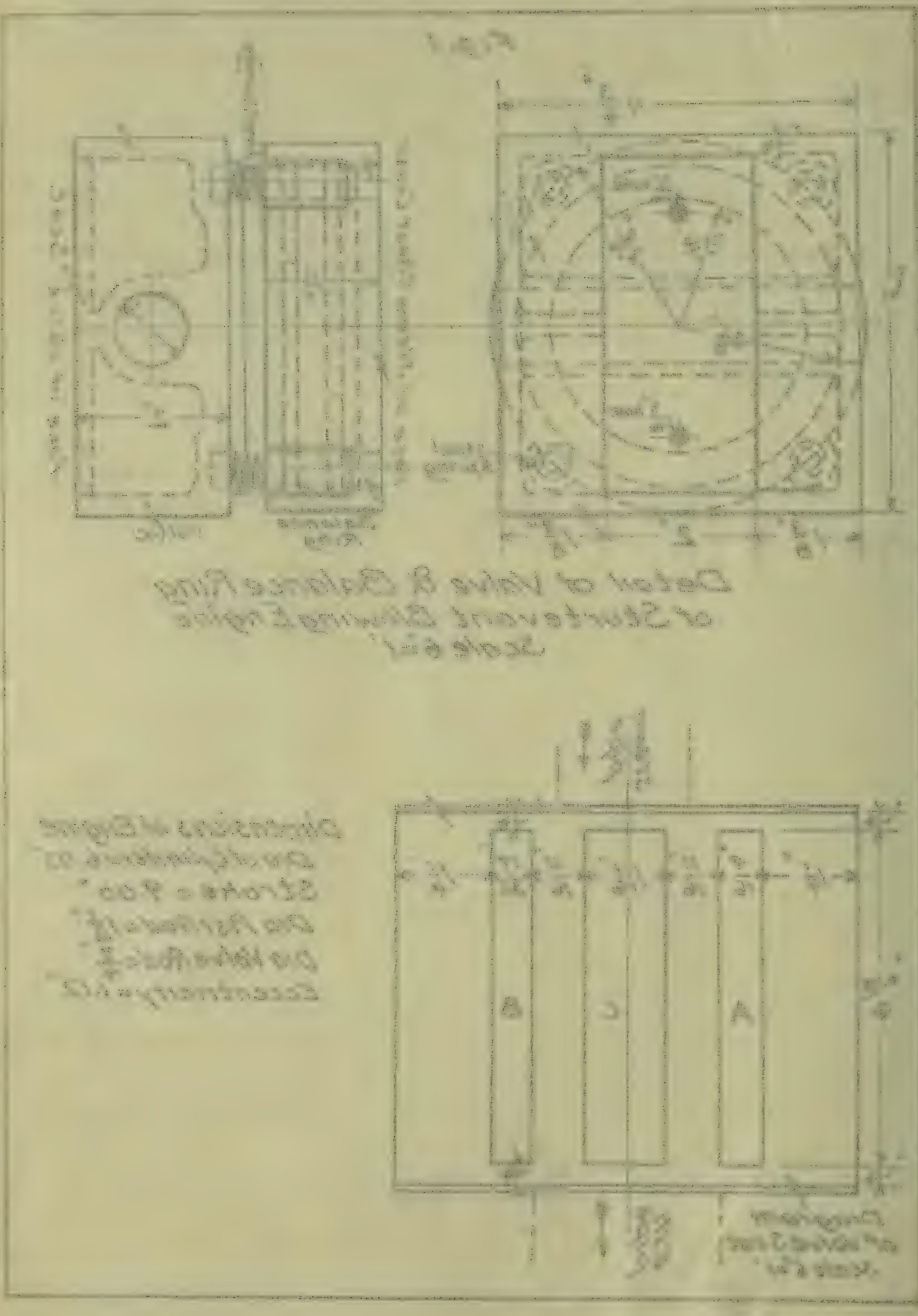


Diagram of Valve Seat
Scale 6"=1'

Dimensions of Engine
Dia of Cylinder = 6.03"
Stroke = 9.00"
Dia Pist Rod = $1\frac{1}{8}$"
Dia Valve Rod = $\frac{3}{4}$"
Eccentricity = 1.12"


Detail of Valve & Balance Ring
of Sturtevant Blowing Engine
Scale 6"=1'
Dimensions of Engine

the back of the valve, the joint being made steam tight by two split rings. It is held against a planed surface on the back of the steam chest cover by four spiral springs. Two small holes in the valve connect the inside of the balance ring to the exhaust cavity in the valve (See Fig 1). The dimensions of the valve and of the valve seat are given in Fig 1.

The losses which were analysed in this thesis were 1- the loss due to the leakage of steam between the steam

chest and the exhaust through the valve. In a valve provided with a balance ring, there is also leakage through the balance ring into the exhaust.

2—The loss due to friction of the valve on its seat and of the balance ring on the steam chest cover.

3— Friction of the eccentric sheave on the strap and of the rocker arm pivots and the valve rod stuffing box. These losses were found in the following way.

①— Leakage of steam.
The two steam passages of

the engine were plugged up by driving wooden plugs in them flush with the seat. The valve was then driven by a motor belted to a wooden pulley fastened to the eccentric sheave. The diameter of the pulley was calculated to make the valve reciprocate with the same frequency as when the engine is running at normal speed. Steam is then admitted to the steam chest, and the steam leaking through to the exhaust is condensed and weighed. In this way the weight of steam leaking through per minute can be found. A

steam consumption test is now run with the steam passages open and thus the percentage of steam wasted by leakage can be found. The pressure in the steam chest during the leakage test is kept the same as the pressure of the admission line on the indicator cards taken during the steam consumption test.

2— The power used in driving the valve is found in the following way. The power supplied to the motor is measured with a Wattmeter. An efficiency test of the motor is also run and a curve between delivered HP and

watts supplied to motor is plotted. The efficiency of the belt drive can be assumed 95%, so that .95 of the delivered horse power is assumed delivered to the pulley on the eccentric. The motor is first run with the valve disconnected. The watts absorbed by the motor are read, and from this the power required to drive the eccentric & rocker connections and to overcome the friction of the stuffing box is calculated. The valve is then set in place, and the power required to drive the valve with different steam pressures in the chest is read

on the Wattmeter. From these tests the percentage of the IHP lost by driving the valve and by friction of the eccentric is found. The coefficient of friction of the valve on its seat can also be calculated.

Description of the Tests

The engine was first overhauled and all the parts cleaned. A surface condenser (S Fig 2) was then connected up to the exhaust. The cooling water was run from the city mains through a hose (H) to the condenser. The condensed steam was

Fig 2
Fig 3

Fig 2

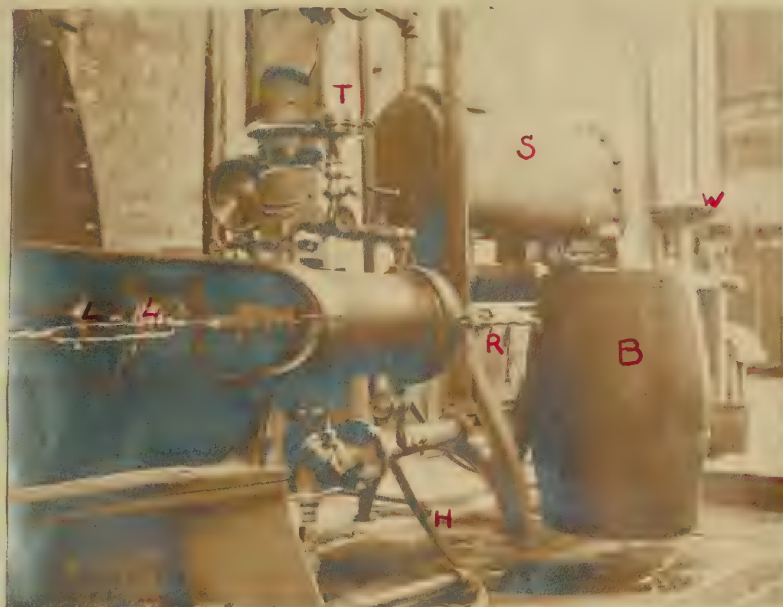


Fig 3

collected in a barrel (B) and weighed on scales (W).

A steam consumption test was first run with the balance ring on the valve. The load was put on the engine by opening the outlet of the blower. This produced a good steady load. The I.H.P. of the engine was found with a Thompson indicator (T). The drum motion was taken right from the cross head, and reduced by a Universal Reducing rig (R). The loop (L) going over the pin in the cross head was made of wire and about 10" long.

after taking a card, a cord tied to the far end of the loop was pulled until the pin on the cross head moved to & fro inside the loop. When taking a card, the cord was released. The revolutions of the engine were recorded on a continuous revolution counter connected by a rod to the top of the eccentric strap. Two steam consumption tests were run with the balance ring on the valve. A one horse power motor was then connected through a switch (S Fig 3) and a starting box (B) to the 110 volt mains of the building. This motor

was belted to a wooden pulley attached to the eccentric sheave. The steam passages of the engine were then plugged up and a leakage test was run.

The balance ring on the valve was then taken off, and the two $\frac{3}{16}$" holes in the valve (See Fig 1) were plugged. A second series of tests similar to the first were then taken with the balance ring off.

Results

① Steam consumption with balance ring on.

Dia of engine cylinder = 6.03"

Stroke = 9.00"

Dia pist rod = 1.125"

$$IHP_{CE} = \frac{PLAN}{33000} = P \times N \times .000624$$

$$IHP_{HE} = \frac{PLAN}{33000} = P \times N \times .000647$$

$P_{CE} = 14.6$# $N = 288$ $P_{HE} = 13.5$#

Water Condensed per minute = 8.36#

$IHP_{CE} = .000624 \times 14.6 \times 288 = 2.62$

$IHP_{HE} = .000647 \times 13.5 \times 288 = \underline{2.51}$

$IHP = 5.13$

Steam per IHPH assuming $x = .98$ =

$$\frac{8.36 \times 60 \times .98}{5.13} = 95.7\text{\# per IHP Hour.}$$

for tabulated results see p 16

② Steam consumption test with balance ring on

$IHP_{CE} = P \times N \times .000624$

$IHP_{HE} = P \times N \times .000647$

$P_{CE} = 16.1 \quad P_{HE} = 16.3 \quad N = 290$

Water per minute = 8.82#

$IHP_{CE} = 16.1 \times 290 \times .000624 = 2.92$

$IHP_{HE} = 16.3 \times 290 \times .000647 = \underline{3.05}$

$IHP = 5.97$

$$\text{Steam per IHPH} = \frac{8.82 \times .98 \times 60}{5.97} = 86.7\#$$

average IHP of tests ① & ②
= 5.55 IHP

average steam per IHPH of ① & ②
= 91.2#

average water per minute
= 8.59#

for Tabulated results see p.16

(1)$_a$ Leakage test with balance ring on valve.

# of water leaking through per min = 3.77

% of steam used in consumption test which leaked through = $\frac{3.77}{8.59}$ = 43.9%

Steam per IHPH wasted through leakage = .439 x 91.2 = 40.0# per IHPH.

Watts supplied to motor running valve = 310 watts. Referring to plate I, we find that 310 watts corresponds to .300 HP used on valve.

% of IHP used to drive valve = $\frac{.3}{5.55}$ = 5.41%

steam per IHPH to drive valve = .0541 x 51.2 = 2.77#

Steam per IHPH for useful work & losses not analised = 48.43#

for tabulated results see p 16

(3) Steam consumption test with balance ring off valve.

$IHP_{CE} = P \times N \times .000624$

$IHP_{HE} = P \times N \times .000647$

$P_{CE} = 14.9$# $P_{HE} = 14.4$# $N = 228$

water per minute = 4.61#

$IHP_{CE} = 14.9 \times 228 \times .000624 = 2.12$

$IHP_{HE} = 14.4 \times 228 \times .000647 = 2.13$

$IHP = 4.25$

Steam per IHPH $= \frac{4.61 \times 60 \times .98}{4.25} = 63.7$#

for tabulated results see p.

(4) Steam consumption test with balance ring off valve

$MEP_{CE} = 18.2$ $MEP_{HE} = 17.6$ $RPM = 248$

water per minute = 5.50

$IHP_{CE} = .000624 \times 18.2 \times 248 = 2.81$

$IHP_{HE} = .000647 \times 17.6 \times 248 = 2.83$

$IHP = 5.64$

Steam per IHPH $= \frac{5.50 \times 60 \times .98}{5.64} = 57.3$#

for tabulated results see p. 16

average IHP of ③ + ④ = 4.94
average water per minute = 5.05#
average steam per IHPH = 60.5#

②a Leakage test with balance ring off.
#of water per min. leakage = .70
% of steam used in ③ & ④ leaking through = 13.9%
# per IHPH lost by leakage = .139 × 60.5 = 8.42#
60.5 − 8.42 = 52.1# per IHPH excluding leakage
watts supplied to motor = 365
from Plate 1, power to drive valve = .365 HP
% of IHP used to drive = $\frac{.365}{4.94}$ = 7.38% of IHP
steam per IHPH used to drive
valve = .0738 × 52.1 = 3.85#
52.1 − 3.85 = 48.25 # per IHPH for useful
work & losses not analysed.
for tabulated results see p 16

Tabulated Results of Steam Consumption Tests

Number of test	#Steam per IHPH	#Water per min	RPM	MEP HE	MEP CE	IHP
1	95.7	8.36	288	13.5	14.6	5.13
2	86.7	8.82	290	16.3	16.1	5.97
3	63.7	4.61	228	14.4	14.9	4.25
4	57.3	5.50	248	17.6	18.2	5.64

Leakage Tests

Number of Test	#of Water per min Leakage	Steam per IHPH Leakage	IP to drive valve	Steam pe IHPH to drive Valve
1a	3.77	40.0	.300	2.77
2a	.70	8.42	.365	3.85

Comparison of Steam Consumption with & without balance Ring on Valve.

	With Balance Rings	Without B.R.
#of steam p IHPH (total)	91.2	60.5
#per IHPH Leaking through Valve	40.0	8.42
#per IHPH to run Valve	2.77	3.85
#per IHPH for useful Work & Losses not analysed	48.43	48.25

Tests made to find the variation of leakage through the valve with different pressures in the steam chest.

The results of these tests are tabulated below and a curve of the results is shown on plate II

Results of tests to find variation of leakage with different pressures in Steam chest. without balance plate.

Number of test	Gauge Pressure in Chest	RPM of Valve	Watts supplied to Motor	Leakage of steam #per min.
1	10	269	293	.987
2	20	267	347	.713
3	30	271	365	.700
4	40	260	393	.638

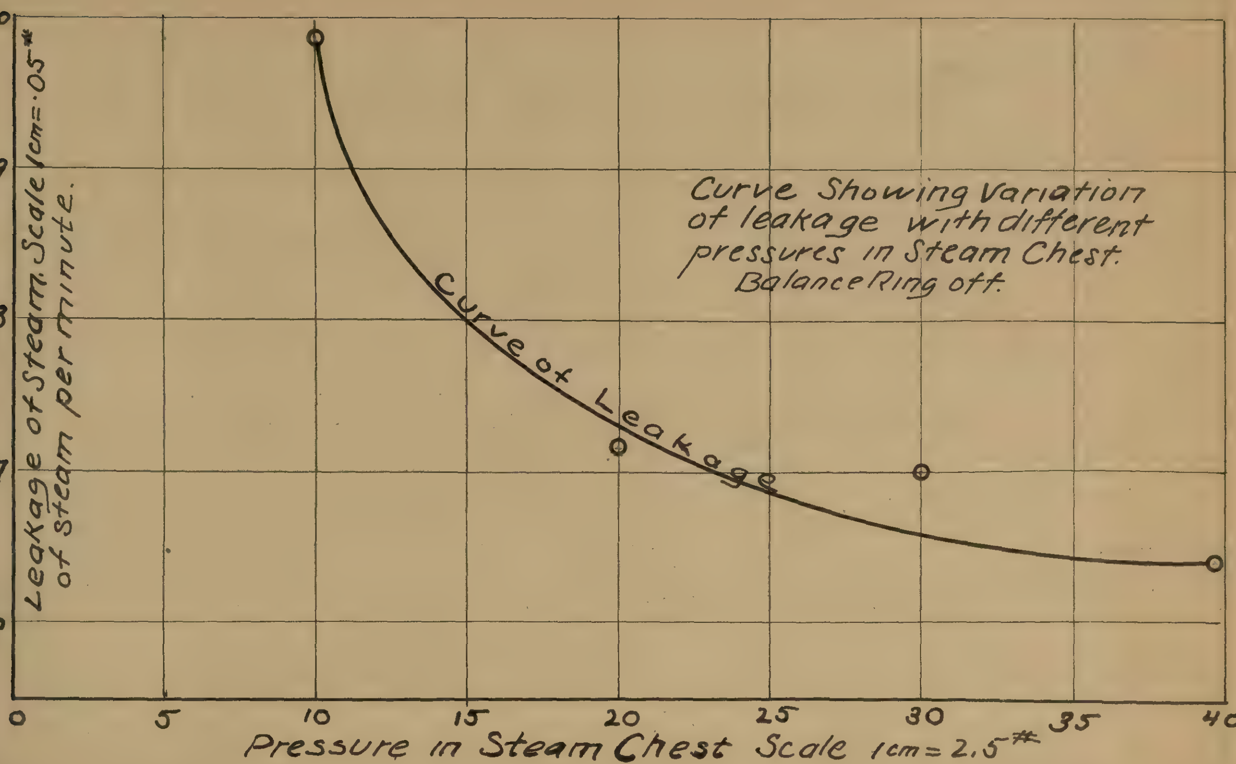
Results of tests to find the variation of the power required to drive the valve with different pressures in the steam chest.

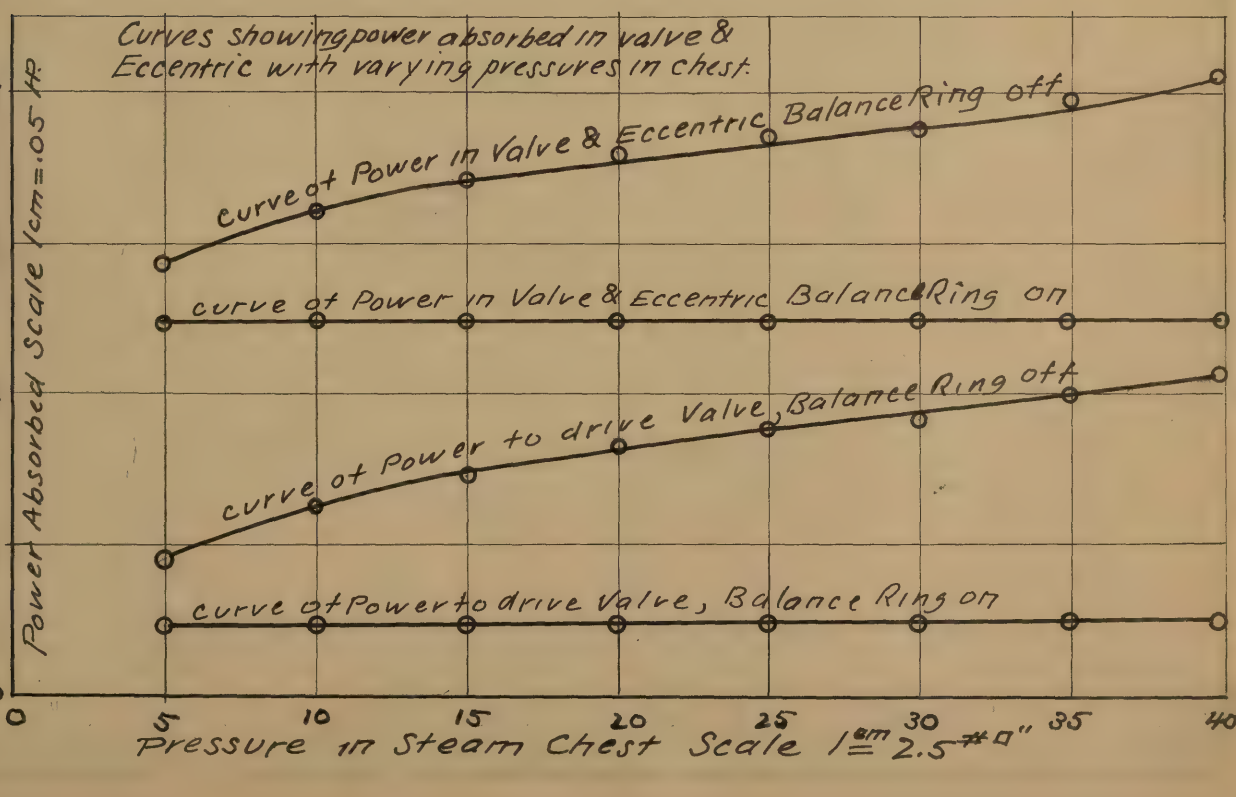
Watts supplied to motor to drive eccentric & overcome rocker arm friction & valve rod stuffing box friction = 210 watts = .195 HP from plate I.

The results are tabulated below & shown on curves plate II

Balance Plate On

Pressure in Chest	Watts supplied to motor	RPM of Valve	HP to drive Valve & Eccentric	HP to drive Valve.
5	255	265	.243	.048
10	260	265	.245	.050
15	260	270	.245	.050
20	265	271	.248	.053
25	265	271	.248	.053
30	265	270	.248	.053
35	265	270	.248	.053.


Curve Showing Variation of leakage with different pressures in Steam Chest. Balance Ring off.
Curve of Leakage
Leakage of Steam. Scale 1cm = ·05# of steam per minute.
Pressure in Steam Chest Scale 1cm = 2.5#
1.0
.9
.8
.7
.6
0
5
10
15
20
25
30
35
40


Curves showing power absorbed in valve & Eccentric with varying pressures in chest.
Curve of Power in Valve & Eccentric Balance Ring off
curve of Power in Valve & Eccentric Balance Ring on
curve of Power to drive Valve, Balance Ring off
curve of Power to drive Valve, Balance Ring on
Power Absorbed Scale 1cm = .05 H.P.
Pressure in Steam Chest Scale 1cm = 2.5#□"
.4
.3
.2
.1
0
0
5
10
15
20
25
30
35
40

Results of Tests to find variation in power to run valve with balance ring off with different pressures in the steam chest. For curves of results see plate 2.

For calculation of μ, see page 20.

Pressure in Chest.	Watts supplied to motor	RPM valve	HP to drive eccentric & valve	HP to drive valve.	μ
5	290	269	.285	.090	.248
10	320	269	.320	.125	.172
15	340	268	.340	.145	.134
20	355	269	.360	.165	.114
25	365	267	.370	.175	.097
30	370	264	.376	.181	.085
35	385	260	.395	.200	.082
40	400	258	.410	.215	.077

Calculation of the coefficient of friction μ of the the valve on its seat. Balance ring off of valve.

eccentricity = 1.12"

area of back of valve = $4.75 \times 5 = 23.8^{\square''}$

Take the test with $10^{\#\square''}$ in chest

$23.8 \times 10 = 238^{\#}$ on back of valve.

HP to drive valve = .125 RPM = 269

$\therefore \quad .125 \times 33\,000 = \dfrac{269 \times 4 \times 1.12}{12} \times F$

$F = 41.1^{\#}$ = force to move valve on seat

$\mu = \dfrac{F}{238} = \dfrac{41.1}{238} = .172.$

Results of efficiency test of motor.

In order to get the delivered HP of the motor from the watts supplied, an efficiency test of the motor was run. The results are

tabulated below.

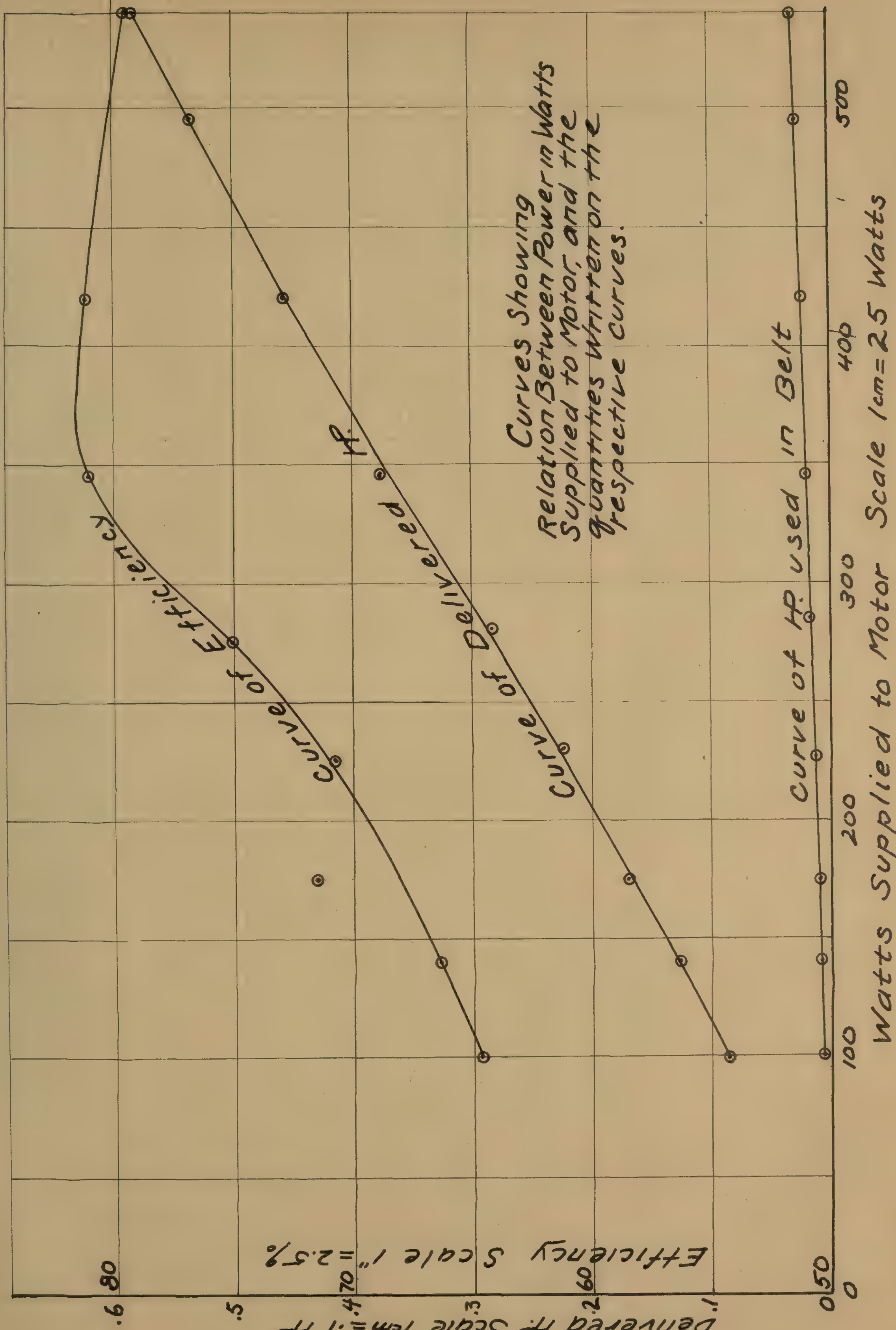
Brakearm = 14.85" = 1.237'

Brake constant = $\frac{1.237 \times 2\pi}{33000}$ = .000235

Efficiency test of Motor.

Watts supplied to Motor	RPM of Motor	HP Delivered	Efficiency of Motor	HP lost on belt
100	1024	.0865	.646	.00432
140	1025	.125	.662	.00625
175	1034	.168	.715	.0084
232	1052	.221	.708	.0110
280	1048	.281	.750	.0140
345	1062	.373	.810	.0186
420	1056	.456	.811	.0228
495	1046	.532	.802	.0266
540	1016	.582	.795	.0291

Plate 1


Curves Showing Relation Between Power in Watts Supplied to Motor, and the Quantities Written on the respective curves.
Curve of Efficiency
Curve of Delivered H.P.
Curve of H.P. used in Belt
Watts Supplied to Motor Scale 1cm=25 Watts
Delivered H.P. Scale 1cm=.1 H.P.
Efficiency Scale 1"=2.5%
0
50
100
200
300
400
500
.1
.2
.3
.4
.5
.6
50
60
70
80

Conclusions

These tests show that a considerable percentage of the steam used in a slide valve engine, never goes into the cylinder of the engine, but leaks right into the exhaust without doing any work. When the valve has balance ring, this loss is considerably greater due to leakage past the balance ring. It is also seen that quite a good deal of power is used in a slide valve engine to run the valve and to overcome the friction of the eccentric and the valve rod stuffing box.

The leakage results obtained in this thesis with the balance ring on the valve are not fair, because the balance ring was not in good condition, there being a crack in it. It was originally intended, after running the tests described, to scrape the valve & seat as true as possible & then to perform another set of similar tests. This was found impossible on account of the extreme thinness of the metal in the valve.

The engine on which these tests were made was installed several years ago

and has not been in use for a considerable time, so that the losses due to leakage and friction are greater than would occur on an engine in constant use and in first class condition.